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Hon. Commissioner of Patents and Trademarks,
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SIR:

CERTIFIED TRANSLATION

I, Mariko Kayama, am an official translator of the Japanese language into the English language and I hereby certify that the attached comprises an accurate translation into English of Japanese Application No. 11-041114, filed on February 19, 1999.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

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[Title of the Invention]

Image Processing Apparatus, Image Processing Method, Learning Apparatus, Learning Method and Recording Medium

[Claims]

[Claim 1] An image processing apparatus comprising:

extraction means for extracting a class tap and a prediction tap in accordance with a pixel of interest included in an input image;

class-code generating means for generating a class code from the class tap extracted by the extraction means;

generating means for generating a prediction coefficient that corresponds to the class code generated by the class-code generating means; and

color-signal generating means for generating a new color signal at the position of the pixel of interest, by using the prediction coefficient generated by the generating means and the prediction tap extracted by the extraction means.

[Claim 2] The image processing apparatus according to claim 1, wherein the color signal representing the pixel of interest is one selected from the group consisting of an R signal, a G signal and a B signal, and the color-signal generating means generates an R signal, a G signal and a B signal at the position of the color signal representing the pixel of interest.

[Claim 3] An image processing method comprising the steps of:

an extraction step of extracting a class tap and a prediction tap in accordance with a pixel of interest included in an input image;

a class-code generating step of generating a class code from the class tap extracted in the extraction step;

a generating step of generating a prediction coefficient that corresponds to the class code generated in the class-code generating step; and

a color-signal generating step of generating a new color signal at the position of the pixel of interest, by using the prediction coefficient generated in the generating step and the prediction tap extracted in the extraction step.

[Claim 4] A medium presenting a computer program designed to cause an image processing apparatus to perform a process comprising:

an extraction step of extracting a class tap and a prediction tap in accordance with a pixel of interest included in an input image;

a class-code generating step of generating a class code from the class tap extracted in the extraction step;

a generating step of generating a prediction coefficient that corresponds to the class code generated in the class-code generating step; and

a color-signal generating step of generating a new color signal at the position of the pixel of interest, by using the prediction coefficient generated in the generating step and the prediction tap extracted in the extraction step.

[Claim 5] A learning apparatus comprising:

generating means for generating a student image from an input teacher image;

first extraction means for extracting a class tap in accordance with a pixel of interest included in the student generated by the generating means;

second extraction means for extracting the value of that pixel of the teacher image which is located at a position corresponding to the pixel of interest included in the student image;

class-code generating means for generating a class code from the class tap extracted by the first extraction means;

calculation means for calculating a prediction coefficient to be used in calculation for generating a new color signal at the position of the pixel of interest included in the student image, by using the class tap extracted by the first extraction means and the pixel value extracted by the second extraction means; and

memory means for storing the prediction coefficient calculated by the calculation means and the class code generated by the class-code generating means, in such a manner that the prediction coefficient and the class code are associated with each other.

[Claim 6] The learning apparatus according to claim 5, wherein the first extraction means extracts the class tap in accordance with the position the pixel of interest takes in the student image and the color the color signal represents.

[Claim 7] A learning method comprising the steps of:

a generating step of generating a student image from an input teacher image;

a first extraction step of extracting a class tap in accordance with a pixel of interest included in the student generated in the generating step;

a second extraction step of extracting the value of that pixel of the teacher image which is located at a position corresponding to the pixel of interest included in the student image;

a class-code generating step of generating a class code from the class tap extracted in the first extraction step;

a calculation step calculating a prediction coefficient to be used in calculation for generating a new color signal at the position of the pixel of interest included in the student image, by using the class tap extracted in the first extraction step and the pixel value extracted in the second extraction step; and

a storing step of storing the prediction coefficient calculated in the calculation step and the class code generated in the class-code generating step, in such a manner that the prediction coefficient and the class code are associated with each other.

[Claim 8] A medium presenting a computer program designed to cause learning apparatus to perform a process comprising:

a generating step of generating a student image from an input teacher image;

a first extraction step of extracting a class tap in accordance with a pixel of interest included in the student generated in the generating step;

a second extraction step of extracting the value of that pixel of the teacher image which is located at a position corresponding to the pixel of interest included in the student image;

a class-code generating step of generating a class code from the class tap extracted in the first extraction step;

a calculation step calculating a prediction coefficient to be used in calculation for generating a new color signal at the position of the pixel of interest included in the student image, by using the class tap extracted in the first extraction step and the pixel value extracted in the second extraction step; and

a storing step of storing the prediction coefficient calculated in the calculation step and the class code generated in the class-code generating step, in such a manner that the prediction coefficient and the class code are associated with each other.

[Detailed Description of the Invention]

[0001]

[Technical Field of the Invention]

The present invention relates to an image processing apparatus, an image processing method, a learning apparatus, a learning method, and a program-presenting medium. More particularly, the invention relates to an image

processing apparatus, image processing method, learning apparatus, a learning method and program-presenting medium, in which color signals are interpolated by means of classification-adaptation process in an image obtained by a CCD (Charge Coupled Device) and a color filter, so that any pixel represented by the image signal may have a red (R) component, a green (G) component and a blue (B) component.

[0002]

[Prior Art]

There are two types of video cameras that have a solid-state image sensor such as a CCD. The first type has one CCD (hereinafter, referred to as "single-plate CCD"). The second type has three CCDs (hereinafter, referred to as "three-plate CCD"). In a three-plate CCD, the three CCDs designed to generate an R signal, a G signal and a B signal, respectively, generates an image signal. The image signal is recorded in a recording medium.

[0003]

In a single-plate CCD, the CCD is arranged in front of a color filter. One of a R signal, G signal and B signal or one of complementary-color signals Ye (Yellow), Cy (Cyanogen) and Mg (Magenta) is input to one pixel on the CCD, thereby generating an image signal. In the single-plate video camera, the image signal generated by the CCD is subjected linear interpolation, thereby providing an image that is similar to the image the three-plate camera provides.

[0004]

[Object of the Invention]

In the above-described single-lens video camera, however, a linear process is carried out to interpolate color signals. The image resolution achieved by the image signals output from the single-plate camera is lower than the image resolution attained by the outputs of a three-plate camera, the resultant image is blurred as a whole due to the influence of the linear process.

[0005]

The present invention has been made in view of the foregoing. The object of the invention is to provide an image that is comparable with an image obtained by reproducing an image signal generated by a three-plate CDD, by utilizing classification-adaptation process to interpolate color signals.

[0006]

[Means to Solve the Problem]

The image processing apparatus as described in claim 1 is comprising: extraction means for extracting a class tap and a prediction tap in accordance with a pixel of interest included in an input image; class-code generating means for generating a class code from the class tap extracted by the extraction means; generating means for generating a prediction coefficient that corresponds to the class code generated by the class-code generating means; and color-signal generating means for generating a new color signal at the position of the pixel of

interest, by using the prediction coefficient generated by the generating means and the prediction tap extracted by the extraction means.

[0007]

The image processing method defined in claim 3 is comprising: an extraction step of extracting a class tap and a prediction tap in accordance with a pixel of interest included in an input image; a class-code generating step of generating a class code from the class tap extracted in the extraction step; a generating step of generating a prediction coefficient that corresponds to the class code generated in the class-code generating step; and a color-signal generating step of generating a new color signal at the position of the pixel of interest, by using the prediction coefficient generated in the generating step and the prediction tap extracted in the extraction step.

[0008]

The medium described in claim 4 presents a computer program designed to cause an image processing apparatus to perform a process. This process comprises: an extraction step of extracting a class tap and a prediction tap in accordance with a pixel of interest included in an input image; a class-code generating step of generating a class code from the class tap extracted in the extraction step; a generating step of generating a prediction coefficient that corresponds to the class code generated in the class-code generating step; and a color-signal generating step of generating a new color signal at the position of the

pixel of interest, by using the prediction coefficient generated in the generating step and the prediction tap extracted in the extraction step.

[0009]

The learning apparatus defined in claim 5 is comprising: generating means for generating a student image from an input teacher image; first extraction means for extracting a class tap in accordance with a pixel of interest included in the student generated by the generating means; second extraction means for extracting the value of that pixel of the teacher image which is located at a position corresponding to the pixel of interest included in the student image; class-code generating means for generating a class code from the class tap extracted by the first extraction means; calculation means for calculating a prediction coefficient to be used in calculation for generating a new color signal at the position of the pixel of interest included in the student image, by using the class tap extracted by the first extraction means and the pixel value extracted by the second extraction means; and memory means for storing the prediction coefficient calculated by the calculation means and the class code generated by the class-code generating means, in such a manner that the prediction coefficient and the class code are associated with each other.

[0010]

The learning method described in claim 7 is comprising: a generating step of generating a student image from an input teacher image; a first extraction step of

extracting a class tap in accordance with a pixel of interest included in the student generated in the generating step; a second extraction step of extracting the value of the pixel of the teacher image which is located at a position corresponding to the pixel of interest included in the student image; a class-code generating step of generating a class code from the class tap extracted in the first extraction step; a calculation step calculating a prediction coefficient to be used in calculation for generating a new color signal at the position of the pixel of interest included in the student image, by using the class tap extracted in the first extraction step and the pixel value extracted in the second extraction step; and a storing step of storing the prediction coefficient calculated in the calculation step and the class code generated in the class-code generating step, in such a manner that the prediction coefficient and the class code are associated with each other.

[0011]

The medium as defined in claim 8 presents a computer program designed to cause learning apparatus to perform a process. This program comprises: a generating step of generating a student image from an input teacher image; a first extraction step of extracting a class tap in accordance with a pixel of interest included in the student generated in the generating step; a second extraction step of extracting the value of that pixel of the teacher image which is located at a position corresponding to the pixel of interest included in the student image; a class-code generating step of generating a class code from the class tap extracted in the first

extraction step; a calculation step calculating a prediction coefficient to be used in calculation for generating a new color signal at the position of the pixel of interest included in the student image, by using the class tap extracted in the first extraction step and the pixel value extracted in the second extraction step; and a storing step of storing the prediction coefficient calculated in the calculation step and the class code generated in the class-code generating step, in such a manner that the prediction coefficient and the class code are associated with each other.

[0012]

In the image processing method of claim 1, image processing method of claim 3 and medium of claim 4, a class tap and a prediction tap are extracted in accordance with a pixel of interest included in the input image, and a new color signal is generated at the position of the pixel of interest, by using the prediction tap extracted in the extraction step and the prediction coefficient corresponding to the class code generated from the class tap extracted.

[0013]

In the learning apparatus of claim 5, learning method of claim 7 and medium of claim 8, a student image is generated from an input teacher image, a class tap is extracted in accordance with a pixel of interest included in the student image, the value of that pixel of the teacher image which is located at a position corresponding to the pixel of interest included in the student image is extracted, a class code is generated from the class tap extracted, a prediction coefficient to be

used in calculation for generating a new color signal at the position of the pixel of interest included in the student image is calculated by using the class tap and the pixel value, and the prediction coefficient and the class code are stored in such a manner that they are associated with each other.

[0014]

[Preferred Embodiment of the Invention]

FIG. 1 is a block diagram showing a digital video camera according to this invention. A lens 2 focuses the light incident to the video camera and applies the light to a CCD 5 through an iris 3 and the color filter 4. In the video camera shown in FIG. 1, the color filter 4 and the CCD 4 are separate components. Nonetheless, they may be combined into one unit.

[0015]

The video camera shown in FIG. 1 has one CCD 5 (a single-plate CCD). The image signal representing the image formed on the CCD 5 is input to a signal-adjusting section 6. The gain of the signal-adjusting section 6 is adjusted so that the output signal may have a constant magnitude. The 1/f noise the CCD 5 generates is removed from the image signal. The output of the signal-adjusting section 6 is input to an A/D converter section 7, which converts the image signal to a digital signal. The digital signal is supplied to an image-signal processing section 8.

[0016]

A sync signal generating section 9 generates a sync signal, which is supplied to the CCD 5, signal-adjusting section 6, A/D converter section 7 and CPU (Central Processing Unit) 10. The CPU 10 drives a motor 11, controlling the iris 3. The CPU 10 drives a motor 12, moving the lens 2 and the like, performing controls such as zooming and focusing. Further, the CPU 10 controls a flash lamp 13, whenever necessary, to apply flashing light.

[0017]

The processing section 8 processes the input signal as will be described later. The signal processed is output to an interface 14. A memory 15, for example a RAM (Random Access Memory) is provided to store signals that are necessary for the section 8 to process the image signal. The image signal processed by the image-signal processing section 8 is stored via an interface 14 into a memory 16. The image signal is supplied from the memory 16 via the interface 14 and recorded in a recording medium 17 that can be removably inserted in the video camera 1.

[0018]

A controller 18 is controlled by the CPU 10, controlling the image-signal processing section 8 and the interface 14. A converter 19 converts the power supplied from the battery 20, to appropriate power, which is supplied to the various components of the camera 1. The battery 20 is removably set in the video camera 1.

[0019]

An operation section 21 comprises operation buttons including a shutter button, a zooming button and the like. A user may operate the operation section 21 to input operation data. The operation data is supplied to the CPU 10. The CPU 10 controls the above-mentioned components in accordance with the operation data input to it.

[0020]

The color filter 4 will be described with reference to FIG. 2. In FIG. 2, G, R, B, M, Y, C and W indicates green, red, blue, magenta, yellow, cyanogen and white, respectively. The color filter 4 is provided in front of the CCD5 and formed integral therewith, so that the CCD 5 may generate color signals for pixels as the color light beams pass through the filter 4. The arrangements of filters shown in FIG. 2(A) to 2(G) includes primary-color filters (R, G, B) each, whereas the arrangements of filers shown in FIG. 2(H) to 2(N) include complementary-color filters (M, Y, C, W, G) each.

[0021]

The following description is based on the assumption that the color filter 4 has the Bayer arrangement illustrated in FIG. 2(A).

[0022]

FIG. 3 is a block diagram showing the image-signal processing section 8. The digital signal output from the A/D converter section 7 is input to the defect

correcting section 31 of the image-signal processing section 8. The defect correcting section 31 detects any defective pixel, such as one not reacting to the input light or one always accumulating an electric charge, irrespective of the input light. The section 31 corrects the input signal to eliminate the influence of the defective pixel detected.

[0023]

The signal input to the image-signal processing section 8 is shifted in the positive direction to prevent any negative value from being discarded. A clamping section 32 processes the signal supplied from the defect correcting section 31, thereby eliminating the shifted component of the image signal. Hence, the proper signal containing a negative value can be obtained from the shifted signal, in order to prevent any negative value from being discarded.

[0024]

The image signal clamped by the clamping section 32 is supplied to a white-balancing section 33. The white-balancing section 33 corrects the gain of the image signal supplied from the clamping section 32, thus adjusting the white balance of the image signal. The image signal having its white balance adjusted is supplied to a gamma-correcting section 34. The gamma-correcting section 34 corrects the input signal in accordance with a gamma curve. The image signal, thus gamma-corrected, is supplied to a block-generating section 35. The block-generating section 35 supplies a class tap (described later) to an ADRC

(Adaptive Dynamic Range Coding) process section 36 and a prediction tap to the adaptation process section 38. The ADRC process section 36 performs ADRC process on the input signal and outputs the signal to a classification process section 37.

[0025]

The classification process section 37 classifies the input signal on the basis of the characteristic (space class) of the signal. The section 37 reads from a memory 39 the coefficient that corresponds to the class number (class code) that represents the result of classification. The adaptation process section 38 uses the coefficient supplied from the memory 39, processing the signal input from block-generating section 35 and outputting the same to a signal-correcting section 40. The signal-correcting section 40 performs a process, such as edge emphasis, on the input signal, and outputs a signal to an RGB matrix 41.

[0026]

The RGB matrix 41 applies a conversion matrix on the input signal (RGB signal), converting the signal to an image signal of a prescribed format, such as a YUV format (composed of luminance Y and color differences U and V). The resultant image signal is output to the interface 14 (FIG. 1).

[0027]

How the video camera 1 shown in FIG. 1 operates will be described, with reference to the flowchart of FIG. 4. The video camera 1 starts photographing the

object in Step S1 when the power switch is turned on. More precisely, the CPU 10 drives the motor 11 and the motor 12, achieving the focusing and adjusting the iris. The light reflected from the object is applied through the lens 2, forming an image of the object on the CCD 5. The image thus formed is displayed by the display device provided in the finder (not shown).

[0028]

To record the image displayed by the display device in the recording medium 17, the user operates the shutter button on the operation section 21. In Step S2, the CPU 10 of the video camera 1 determines whether the shutter button has been operated or not. Steps S1 and S2 are repeated until it is determined that the shutter button has been operated. Then, the process goes to step S3.

[0029]

In Step S3, the analog signal representing the image formed by the CCD 5 is input to the signal-adjusting section 6. The section 6 adjusts the gain of the image signal, thereby removing noise from the image signal. The image signal is supplied to the A/D converter section 7, which converts the image signal to a digital signal. The digital signal is output to the image-signal processing section 8. In Step S4, the image-signal processing section 8 processes the digital signal input to it.

[0030]

FIG. 5 is a flowchart explaining in detail how the image-signal processing

section 8 processes an image signal in Step S4. The digital signal input to the image-signal processing section 8 is input to the defect correcting section 31. In Step S11, the defect correcting section 31 corrects the input signal, eliminating the defects in the image signal so that the input signal may not be adversely influenced by the defects. The signal thus corrected is input to the clamping section 32. In Step S12, the clamping section 32 performs a process on the input signal, thereby eliminating that component of the image signal which has been shifted tin the positive direction. A signal having a negative value is thereby obtained.

[0031]

The signal output from the clamping section 32 is input to the white-balancing section 33. In Step S13, the white-balancing section 33 corrects the white balance of the image signal. The signal thus corrected in white balance is output to the gamma-correcting section 34. In Step S14, the gamma-correcting section 34 corrects the input signal in accordance with a gamma curve. The signal, gamma-corrected, is output to the block-generating section 35.

[0032]

In Step S15, the block-generating section 35 extracts a class tap and a prediction tap from the signal input from the gamma-correcting section 34. FIG. 6 shows the structure of a prediction tap. The prediction tap is composed of 9 pixels forming a 3×3 matrix, the central pixel being the pixel of interest (i.e., the pixel to be processed). The block-generating section 35 extracts the

prediction tap for each pixel of interest, thereby generating a plurality of blocks, each consisting of 9 pixels. The pixel of interest in each block may be any one of the pixels that constitute one frame.

[0033]

The block of the class tap, output from the block-generating section 35, is output to the ADRC process section 36. The block of the prediction tap is then output to the adaptation process section 38. In Step S16, the ADRC process section 36 performs ADRC process. The ADRC process is to remove redundancy in the level direction from the signal, by using the local correlation of pixels, thereby to achieve data compression.

[0034]

The operation given by the following equations is carried out:

$$Q = \{(L - MIN + 0.5) \times 2^n / DR] \quad .... \quad (1)$$

$$DR = MAX - MIN + 1 \quad .... \quad (2)$$

where DR is the dynamic range of the region, n is the number of bits allocated to the region, L is the signal level of pixels present in the region, and Q is the re-quantized code.

Here, (z) means the discarding fractions and indicates the largest integer below z. MIN and MAX are the minimum value and maximum value in the image data for the nine pixel image data items of the prediction tap. If the ADRC process provides nine pixel data items, each consisting of eight bits (n = 8), each

data item will be compressed to one bit. Hence, the space class calculated by the ADRC process section 36 is expressed by nine bits.

[0035]

In Step S17, the classification process section 37 generates a class code that corresponds to the space class output from the ADRC process section 36. The section 37 reads the prediction coefficient corresponding to the class code, from the coefficient memory 39, and supplies the coefficient to the adaptation process section 38. In Step S18, the adaptation process section 38 performs an adaptation process, by using the prediction coefficient input from the coefficient memory 39 and the prediction tap which corresponds to the prediction coefficient and which has been supplied from the block-generating section 35.

[0036]

The adaptation process is to apply the prediction coefficient and prediction tap, which correspond to the space class of the pixel of interest, thus performing operations on a linear combination model represented by the following equation (3):

$$E\,[y] = w_1\,x_1 + w_2\,x_2 + w_3\,x_3 \ldots \quad + w_i\,x_i \qquad \ldots. \qquad (3)$$

where w_1, w_2, w_3, ... w_i are prediction coefficients, x_1, x_2, x_3, ... x_i are the pixel data items supplied and E [y] is the predicted value the image data "y" has with respect to the pixel of interest. The suffix "i" ranges from 1 to 9 because it indicates the number of the image data items forming the block.

[0037]

The adaptation process section 38 performs the adaptation process. If the pixel signal representing the pixel of interest is an R signal, a G signal and a B signal will be generated at the position of the pixel represented by the R signal. If the pixel signal is a G signal or a B signal, an R signal, a G signal and a B signal will be generated at the position of the pixel represented by the G signal or the B signal. Consider a one-frame image signal that is composed of 8 $\times$ 6 pixels as shown in FIG. 7(A). When the 8 $\times$ 6 pixels sequentially subjected to the adaptation process, each as a pixel of interest, 8 $\times$ 6 R signals are obtained as shown in FIG. 7(B), 8 $\times$ 6 G signals are obtained as shown in FIG. 7(C), and 8 $\times$ 6 B signals are obtained as shown in FIG. 7(D). In other words, an image signal is generated, which is equivalent to one output by the CCD of a three-plate camera.

[0038]

FIG. 8 is diagrams the prediction coefficients (w_1 to w_9) stored in the coefficient memory 39. In the case of FIG. 8(A), the pixel of interest is a G signal, two B signals are arranged above and below the pixel of interest, respectively, two R signals are arranged to the left and right of the pixel of interest, respectively, and four G signals are arranged at upper-left, upper-right, lower-left and lower-right positions with respect to the pixel of interest, respectively. The prediction coefficients of this set are used to generate an R signal at the position of

the G signal that is the pixel of interest.

[0039]

In the case of FIG. 8(B), the pixel of interest is a G signal as in FIG. 8(A). An R signal will be generated at the position of this pixel of interest. Two R signals are arranged above and below the pixel of interest, i.e., a G signal, respectively, and two B signals are arranged to the left and right of the pixel of interest, respectively. In the case of FIG. 8(C), the pixel of interest is a B signal, two G signals are arranged to the left and right of the pixel of interest, respectively, two G signals are arranged above and below the pixel of interest, respectively, and four R signals are arranged at upper-left, upper-right, lower-left and lower-right positions with respect to the pixel of interest, respectively. The prediction coefficients of this set are used to generate an R signal at the position of the B signal that is the pixel of interest.

[0040]

In Step S18 shown in the flowchart of FIG. 5, the ADRC process section 38 performs an ADRC process. Then, in Step S19, it is determined whether or not the adaptation process has been performed on all blocks. If it is determined that the adaptation process has not been performed on all blocks, the operation returns to goes to Step S16, and the subsequent steps will be processed.

[0041]

If it is determined in Step S19 that the adaptation process has been

performed on all blocks, the operation goes to Step S20. In Step S20, the correcting section 40 performs correction, such as edge correction, on the input signal (thus forming an image), and supplies the signal to the RGB matrix 41. In Step S21, the RGB matrix 41 converts a color space (to the format suitable for the recording medium 15). The signal thus processed by the image-signal processing section 8 is stored into the memory 16 via the interface 14.

[0042]

In Step S5 (FIG. 4), the image signal stored in the memory 16 is recorded in the recording medium 17.

[0043]

In the video camera 1 according to this invention, a classification process is effected, generating color signals R, G and B that are equivalent to the outputs of the CCD of a three-plate camera. Thus, the edge parts and fine parts of the image increase in sharpness, and the S/N ratio of the image signal increases.

[0044]

As indicated above, the prediction coefficients, which have been acquired by learning, are stored in the coefficient memory 39. How the learning is effected will be explained. FIG. 9 is a block diagram showing a learning apparatus 51 that acquires sets of prediction coefficients by learning. In the learning apparatus 51, the input digital image data (teacher image) is supplied to an extraction section 52 and a teacher-image block generating section 53. The extraction section 52 is a

filter similar to an optical low-pass filter (which can serve to provide an image by a video camera that stores prediction coefficients calculated). The section 52 extracts pixels from the input teacher image, in accordance with the arrangement of the color filters used in the video camera, thereby generating a student image. The student image is output to a student-image block generating section 54.

[0045]

The teacher image is an image that has a resolution similar to that of the CCD output of a single-plate camera. In other words, it has a lower resolution than a image signal generated by a three-plate camera. Thus, the teacher image consists of pixels, each having a R component, a G component and a B component. By contrast, the student image consists of pixels, each consisting of only one of the R, G and B components.

[0046]

The student-image block generating section 54 extracts the class tap related to the pixel of interest, from the student-image signal input to it. The section 54 converts the student-image signal to a block, which is supplied to an ADRC process section 55 and an operating section 57. The ADRC process section 55 performs an ADRC process on the input signal and supplies the signal to a classification process section 56. The classification process section 56 generates a class code. The class code is output to the operating section 57.

[0047]

The teacher-image block generating section 53 extracts the value of an pixel from the input teacher-image signal. This pixel is located at a position that corresponds to the pixel the student-image block generating section 54 has set as the pixel of interest. The value of the pixel is supplied to the operating section 57. The operating section 57 performs an operation (later described) on the signals input from the teacher-image block generating section 53, student-image block generating section 54 and classification process section 56. The result of the operation is supplied to a learned data memory 58 and stored into the memory 58. The data stored in the learned data memory 58 is output to an operating section 59. The section 59 performs an operation on the data, calculating a prediction coefficient. The prediction coefficient calculated by the operating section 59 is stored into a coefficient memory 60.

[0048]

How the learning apparatus 51 shown in FIG. 9 functions will be explained with reference to the flowchart of FIG. 10. In Step S31, digital image data is input to the learning apparatus 51. The input image input is supplied to the extraction section 52 and teacher-image block generating section 53. The image data supplied is one representing an image that is comparable in quality, with images photographed by a three-plate CCD. In Step S32, the extraction section 52 converts the image data to image data that represents an image having quality comparable with that of an image photographed by a video camera that

incorporates a single-plate CCD.

[0049]

The image data generated by a video camera having a three-plate CCD (i.e., data of an teacher image) contains pixel data items, each consisting of three signals, R, G and B signals. By contract, the image data generated by a video camera having a single-plate CCD (i.e., data of an student image) contains pixels data items, each composed of one signal, R, G, or B signal. The extraction section 52 performs thinning, equivalent to the function of the color filters used in the single-plate CCD, thereby generating a student image from a teacher image.

[0050]

The student image generated by the extraction section 52 is output to the student-image block generating section 54. In Step S33, the student-image block generating section 54 extracts a class tap from the student image, on the basis of the pixel of interest. The teacher-image block generating section 53 extracts from the teacher image the pixel value of the pixel located at the position corresponding to the pixel the student-image block generating section 54 has set as the pixel of interest.

[0051]

FIG. 11 shows examples of class taps used in the student-image block generating section 54. The class taps 1 to 3 shown in FIGS. 11(A) to 11(F) are used to calculate prediction coefficients that are applied to generate an R signal or

a B signal at the position of the pixel of interest (the pixel shaded in the figures). The class tap 4 shown in FIGS. 11(G) and 11(H) is used to calculate prediction coefficients that are applied to generate a G signal at the position of the pixel of interest.

[0052]

The pixels of interest for the class taps 1 and 2 are G signals. The class tap 1 shown in FIG. 1(A) is used to calculate prediction coefficients for generating an R signal at the position of the G signal for the pixel of interest. The class tap 1 is composed of nine pixels (including the pixel of interest). More precisely, it consists of two R-signal pixels arranged to the left and right of the G-signal pixel (i.e., the pixel of interest), two R-signal pixels arranged above and below the first R-signal pixel and spaced apart therefrom by one pixel-distance, respectively, two R-signal pixels arranged above and below the second R-signal pixel and spaced apart therefrom by a one-pixel distance, respectively, and two R-signal pixel arranged to the left of the first R-signal pixel and right of the second R-signal pixel and spaced apart therefrom by a one-pixel distance, respectively.

[0053]

The class tap 1 shown in FIG. 11(B) is used to calculate a set of prediction coefficients that will be applied to generate a B signal at the position of the G signal for the pixel of interest. This class tap 1 has the same structure as the class tap 1 shown in FIG. 11(A), but B signals replace the R signals.

[0054]

The class tap 2 shown in FIG. 11(C) is used to calculate prediction coefficients that will be applied to generate an R signal at the position of the G signal for the pixel of interest. The class tap 2 is composed of nine pixels. To be more specific, it consists of two R-signal pixels arranged above and below the G-signal pixel of interest, respectively, two R-signal pixels arranged above the first R-signal pixel and below the second R-signal pixel and spaced therefrom by a one-pixel distance, respectively, two R-signal pixels arranged to the left and right of the first R-signal pixel and spaced therefrom by a one-pixel distance, respectively, and two R-signal pixels arranged to the left and right of the second R-signal pixel and spaced therefrom by a one-pixel distance, respectively. The class tap 2 shown in FIG. 11(D) is used to calculate prediction coefficients that will be applied to generate a B signal at the position of the G signal for the pixel of interest. The class tap 2 has the same structure as the class tap 2 of FIG. 11(C), except that B signals replace the R signals of the class tap 2 of FIG. 11(C).

[0055]

The class tap 3 shown in FIG. 11(E) is used to calculate a set of prediction coefficients that will be applied to generate an R signal at the position of the G signal for the pixel of interest. The class tap 3 is composed of nine pixels. More precisely, it consists of four R-signal pixels arranged at upper-left, upper-right, lower-left and lower-right positions with respect to the G-signal pixel of interest,

respectively, an R-signal pixel arranged above the first R-signal pixel and spaced therefrom by a one-pixel distance, an R-signal pixel arranged to the left of the second R-signal pixel and spaced therefrom by a one-pixel distance, an R-signal pixel arranged to the below the third R-signal pixel and spaced therefrom by a one-pixel distance, and an R-signal pixel arranged to the right of the fourth R-signal pixel and spaced therefrom by a one-pixel distance. The class tap 3 shown in FIG. 11(F) is used to calculate predictions coefficients that will be applied to generate a B signal at the position of an R signal for the pixel of interest. Its structure is the same as that of the class tap 3 shown in FIG. 11(E), except that B signals replace the R signals of the class tap 3 of FIG. 11(E).

[0056]

The class tap 4 shown in FIG. 11(G) is applied to calculate prediction coefficients that will be applied to generate a G signal at the position of the R signal for the pixel of interest. This class tap 4 is composed of nine pixels. More correctly, it has four G-signal pixels arranged at upper-left, upper-right, lower-left and lower-right positions with respect to the R-signal pixel of interest, respectively. Further, it has a G-signal pixel arranged at an upper-left position with respect to the first G-signal pixel and spaced therefrom by a one-pixel distance, a G-signal pixel arrange at an lower-left position with respect to the second G-signal pixel and spaced therefrom by a one-pixel distance, a G-signal pixel arranged at an lower-right position with respect to the third G-signal pixel

and spaced therefrom by a one-pixel distance, and a G-signal pixel arranged at an upper-right position with respect to the fourth G-signal pixel and spaced therefrom by a one-pixel distance. The class tap 4 shown in FIG. 11(H) is identical in structure to the class tap 4 shown in FIG. 11(G), except that a B signal for the pixel of interest replaces the R signal for the pixel of interest in the class tap 4 of FIG. 11(G).

[0057]

The student-block generating section 54 extracts a class tap from the pixels that have been extracted by using the above-mentioned class taps 1 to 4, in accordance with the color of the pixel of interest and the color of the pixel generated at the position of the pixel of interest. The class tap extracted is output to The ADRC process section 55 and the operating section 57. In Step S34, the ADRC process section 55 carries out the ADRC process on the color signals of the class tap input, generating a space class. The space class is output to the classification process section 56. In Step S35, the classification process section 5 generates a class code for the space class input to it. The class code is output to the operating section 57.

[0058]

In Step S36, the operating section 57 effects an addition process in a normal equation, on the data items input from the teacher-image block generating circuit 53, student-image block generating section 54 and classification process

section 56. The normal equation, which is used to calculate prediction coefficients, will be explained.

[0059]

The predicted value E [y] of the image data y of the pixel of interest may be obtained by a linear combination model represented by a combination of the input data items x1, x2, x3, ... for the pixel (including the pixel of interest) located at a position adjacent to the pixel of interest, in both time and space and the specified prediction coefficients w1, w2, w3 ... . In this case, the predicted value E [y] can be represented by the equation (3) described above.

[0060]

The equation (3) can be generalized as follows. Let us define a set of prediction coefficients w, a set of input data items x, and a set of predicted values E [y] as a matrix W, a matrix X and a matrix Y, respectively.:

[Math 1]

$$X = \begin{bmatrix} X_{11} & X_{12} & \cdots\cdots & X_{1n} \\ X_{21} & X_{22} & \cdots\cdots & X_{2n} \\ \cdots\cdots & \cdots\cdots & \cdots\cdots & \cdots\cdots \\ X_{m1} & X_{m2} & \cdots\cdots & X_{mn} \end{bmatrix}$$

$$W = \begin{bmatrix} W_1 \\ W_2 \\ \cdots\cdots \\ W_n \end{bmatrix}, Y = \begin{bmatrix} E[y_1] \\ E[y_2] \\ \cdots\cdots \\ E[y_m] \end{bmatrix}$$

Then, the observation equation represented by the following equation (4) is established:

Observation equation : XW = Y .... (4)

[0061]

The least squares method is applied to the observation equation, thereby to obtain a predicted value E [y] that is similar to the image data of the pixel of interest. Let us define a matrix Y' consisting of image data items y for the pixel of interest in the teacher image, and a matrix E consisting of differences e, each between an image data item y and the corresponding predicted value E [y], as follows:

[Math 2]

$$E = \begin{bmatrix} e_1 \\ e_2 \\ \cdots \\ e_m \end{bmatrix}, Y' = \begin{bmatrix} y_1 \\ y_2 \\ \cdots \\ y_m \end{bmatrix}$$

Then, the following difference equation (5) derives from the equation (4):

Difference equation: XW = Y + E .... (5)

[0062]

The prediction coefficient w_i that is applied to find the predicted value E [y] similar to the image data y can be obtained by minimizing a square of the difference that is given as follows:

[Math 3]

$$\sum_{i=1}^{m} e_i^2$$

Thus, the prediction coefficient w_i is the optimal value for obtaining a predicted value E [y] similar to the image data y if we get 0 by differentiate the square of the difference, with this prediction coefficient w_i, that is, if the prediction coefficient w_i satisfies the following equation (6):

[Math 4]

$$e_1 \frac{\partial e_1}{\partial W_i} + e_2 \frac{\partial e_2}{\partial W_i} + \ldots + e_m \frac{\partial e_m}{\partial W_i} = 0 (i = 1,2,\ldots,n) \quad \ldots (6)$$

[0063]

Differentiating the equation (5), we obtain the following equation (7):

[Math 5]

$$\frac{\partial e_i}{\partial w_1} = X_i 1, \frac{\partial e_i}{\partial w_2} = X_i 2, \ldots\ldots \frac{\partial e_i}{\partial w_n} = X_{in}, (i = 1,2,\ldots,m) \quad \ldots (7)$$

[0064]

The following equation (8) derives from the equations (6) and (7):

[Math 6]

$$\sum_{i=1}^{m} e_i x_i 1 = 0, \sum_{i=1}^{m} e_i x_i 2 = 0, \ldots\ldots \sum_{i=1}^{m} e_i x_{in} = 0 \quad \ldots (8)$$

[0065]

Consider the learned data x, prediction coefficient w, teacher-image pixel

data y and difference e, all in the difference equation (5). Then, the following normal equation (9) derives from the equation (8):

[0066]

[Math 7]

$$
\begin{cases}
\left(\sum_{i=1}^{m} x_i 1 x_{i1}\right) w_1 + \left(\sum_{i=1}^{m} x_{i1} x_{i2}\right) w_2 + \ldots. + \left(\sum_{i=1}^{m} x_{i1} x_{in}\right) w_n = \left(\sum_{i=1}^{m} x_{i1} y_i\right) \\
\left(\sum_{i=1}^{m} x_{i2} x_{i1}\right) w_1 + \left(\sum_{i=1}^{m} x_{i2} x_{i2}\right) w_2 + \ldots. + \left(\sum_{i=1}^{m} x_{i2} x_{in}\right) w_n = \left(\sum_{i=1}^{m} x_{i2} y_i\right) \\
\qquad\qquad\qquad\qquad \cdots\cdots\cdots\cdots \\
\left(\sum_{i=1}^{m} x_{i1} x_{i1}\right) w_1 + \left(\sum_{i=1}^{m} x_{in} x_{i2}\right) w_2 + \ldots. + \left(\sum_{i=1}^{m} x_{in} x_{in}\right) w_n = \left(\sum_{i=1}^{m} x_{in} y_i\right)
\end{cases}
\quad \ldots \quad (9)
$$

[0067]

The normal equation (9) can be set in the same number as the prediction coefficients that should be obtained. Hence, it is possible to obtain an optimal prediction coefficient w, by solving the equation (9).

[0068]

In Step S36, the operating section 57 performs the process of setting the normal equation (9). The coefficients of the matrix of the normal equation (9) thus set are sequentially stored into the learned data memory 58. In Step S37, it is determined whether the process described above has been performed for all blocks or not. If there are any blocks not processed yet, the operation returns to Step S36.

In this case, Steps S36 and S37 are repeated.

[0069]

If it is determined in Step S37 that all blocks have been processed, the operation goes to Step S38. In Step S38, the operating section 59 solves the normal equation (i.e., equation (9)) stored in the learned data memory 58, by means of, for example, the Gauss-Jordan elimination or the Kolensky decomposition. The section 59 calculates prediction coefficients.

[0070]

The prediction coefficients, thus calculated, are stored into the coefficient memory 60 in Step S39. In the memory 60, they are associated with the class code output from the classification process section 56. Note that the prediction coefficients stored in the memory 60 are identical to the prediction coefficients stored in the memory 39 of the image-signal processing section 8 shown in FIG. 3. The adaptation process section 38 performs the adaptation process on the pixel of interest, using the prediction coefficients stored in the memory 39 by means of the linear combination model represented by the following equation (3)

[0071]

As described above, the prediction tap the image-signal processing section 8 uses to perform the adaptation process and the class tap the learning apparatus 51 uses to calculate a set of prediction coefficients are of different structures. Nonetheless, the prediction tap and the class tap may be of the same structure.

Furthermore, the structures of the prediction tap and class tap are not limited to those described above.

[0072]

As has been indicated, the color-coding filter is one having a color-filter array of Bayer arrangement. Any other type of a color-coding filter can be used instead, in the present invention. The ADRC process is carried out to generate the quantized code. Instead, DCT (Discrete Cosine Transform), VQ (Vector Quantization), DPCM (Differential Pulse Code Modulation), BTC (Block Trancation Coding), non-linear quantization, or the like may be performed to compress data.

[0073]

The computer program that implements these processes is recorded in a recording medium. The recording medium storing this program is presented to users, in the form of a magnetic disk, a CD-ROM or the like. Moreover, the program can be transmitted to users through networks such as the Internet and digital-communications satellites.

[0074]

[Advantageous Effect of the Invention]

With the image processing apparatus described in claim 1, the image processing method described in claim 3 and the medium according to claim 4, a class tap and a prediction tap are extracted in accordance with a pixel of interest

included in an input image, a class code is generated from the class tap, the prediction coefficient and predicted tap, both corresponding to the class code are used, thereby generating a new color signal at the position of the pixel of interest. It is therefore possible to provide an image of high resolution.

[0075]

With the image processing apparatus described in claim 5, the image processing method described in claim 7 and the medium according to claim 8, a student image is generated from an input teacher image, a class tap is extracted in accordance with a pixel of interest included in the student image, the value of that pixel of the teacher image which is located at a position corresponding to the pixel of interest included in the student image is extracted, a class code is generated from the class tap extracted, a prediction coefficient to be used in calculation for generating a new color signal at the position of the pixel of interest included in the student image is calculated by using the class tap and the pixel value, and the prediction coefficient calculated in the calculation step and the class code generated in the class-code generating step are stored in such a manner that the prediction coefficient and the class code are associated with each other. Thus, it is possible to calculate prediction coefficients that may be used in an image processing apparatus to process data to provide an image of high resolution.

[Brief Description of the Drawings]

[FIG. 1]

A block diagram of a video camera 1 according to the present invention.

[FIG. 2]

A diagram explaining the color filter 4 shown in FIG. 1.

[FIG. 3]

A block diagram of the image-signal processing section 8 shown in FIG. 1.

[FIG. 4]

A flowchart for explaining how the video camera shown in FIG. 1 operates.

[FIG. 5]

A flowchart explaining, in detail, Step S4 shown in FIG. 4.

[FIG. 6]

A diagram explaining a prediction tap.

[FIG. 7]

A diagram explaining the adaptation process.

[FIG. 8]

A diagram showing an example of a prediction coefficient.

[FIG. 9]

A block diagram illustrating the structure of a learning apparatus.

[FIG. 10]

A flowchart explaining the operation of the learning apparatus shown in FIG. 9.

[FIG. 11]

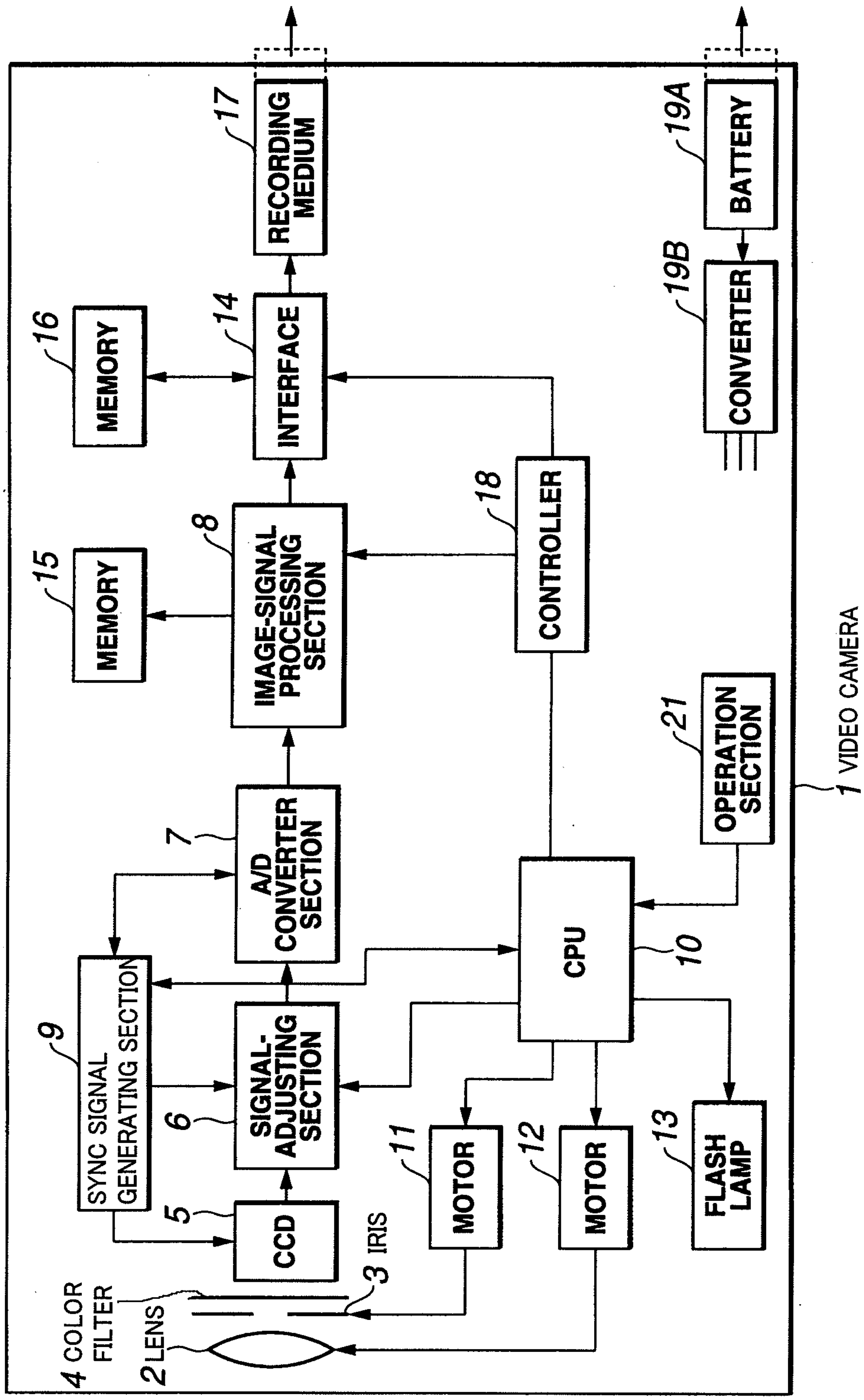
A diagram explaining a class tap.

[Explanation of Referenced Numerals]

8 image-signal processing section ; 35 block-generating section ; 36 ADRC process section ; 37 classification process section ; 38 adaptation process section; 39 coefficient memory ; 51 learning apparatus ; 52 extraction section; 53 teacher-image block generating section ; 54 student-image block generating section ; 55 ADRC process section ; 56 classification process section ; 57 operating section ; 58 learned data memory ; 59 operating section ; 60 coefficient memory

[Document Name] DRAWING

[FIG. 1]



[FIG. 2]

(A)

G	R	G	R
B	G	B	G
G	R	G	R
B	G	B	G

BAYER

(B)

G	R	G	B
R	G	B	G
G	R	G	B
R	G	B	G

INTERLINE

(C)

G	R	G	R
G	B	G	B
G	R	G	R
G	B	G	B

G STRIPE,
RB CHESSBOARD

(D)

G	R	G	B
G	B	G	R
G	R	G	B
G	B	G	R

G STRIPE,
RB PERFECT CHESSBOARD

(E)

G	R	B	G
G	R	B	G
G	R	B	G
G	R	B	G

STRIPE

(F)

G	R	B	G
R	B	G	R
B	G	R	B
G	R	B	G

SLANG STRIPE

(G)

G	B	G	B
G	R	G	R
G	B	G	B
R	G	R	G

PRIMARY
COLOR-DIFFERENCE

(H)

M	G	M	G
C	Y	C	Y
M	G	M	G
Y	C	Y	C

SEQUENCE OF
FIELD COLOR-
DIFFERENCES

(I)

YM	YM	YM	YM
YG	CM	YG	CM
YM	CG	YM	CG
YG	CM	YG	CM

SEQUENCE OF
FRAME COLOR-
DIFFERENCES

(J)

W	C	G	Y
G	Y	W	C
W	C	G	Y
G	Y	W	C

MOS TYPE

(K)

W	G	W	G
C	Y	C	Y
W	G	W	G
C	Y	C	Y

MODIFIED
MOS TYPE

(L)

W	G	W	G
C	Y	C	Y
W	G	W	G
C	Y	C	Y

FRAME
INTERLEAVE

(M)

G	C	G	C
G	Y	G	Y
G	C	G	C
Y	G	Y	G

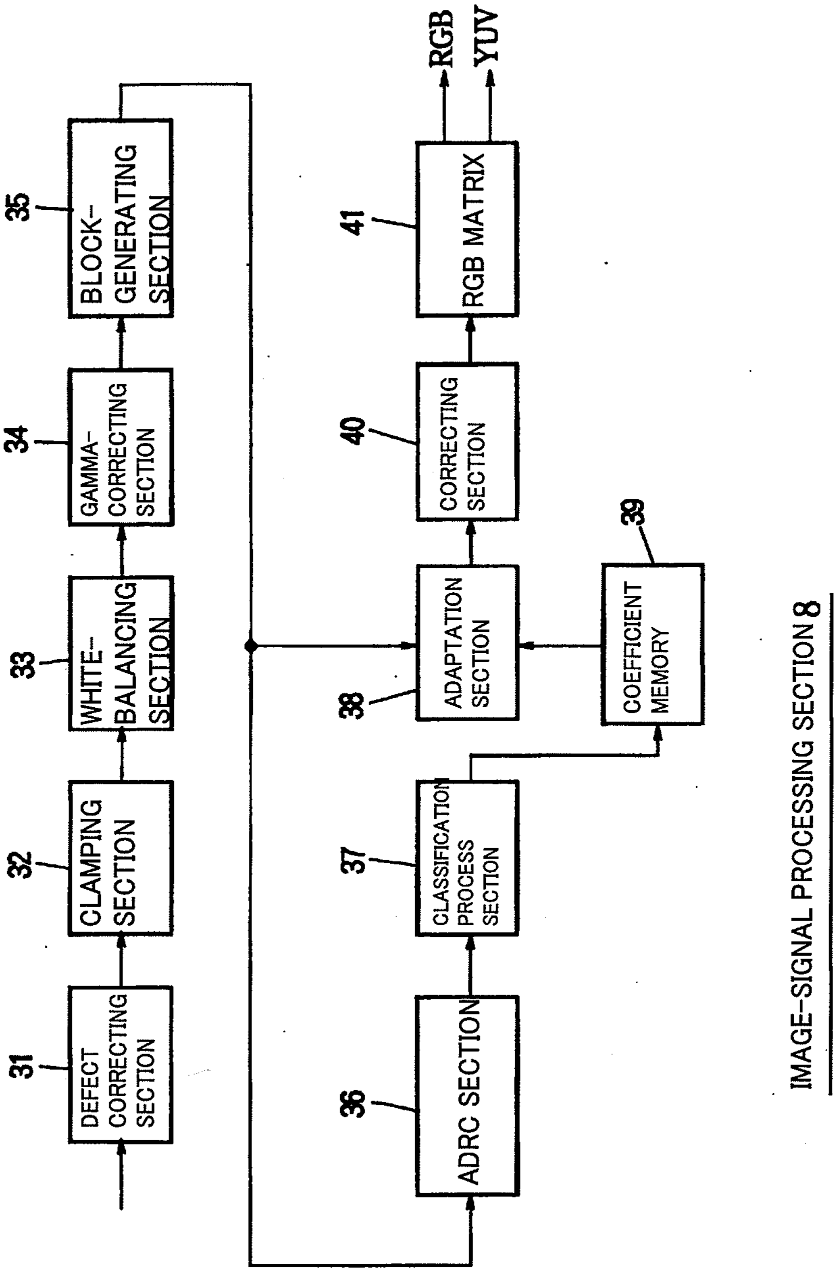
FIELD
INTERLEAVE

(N)

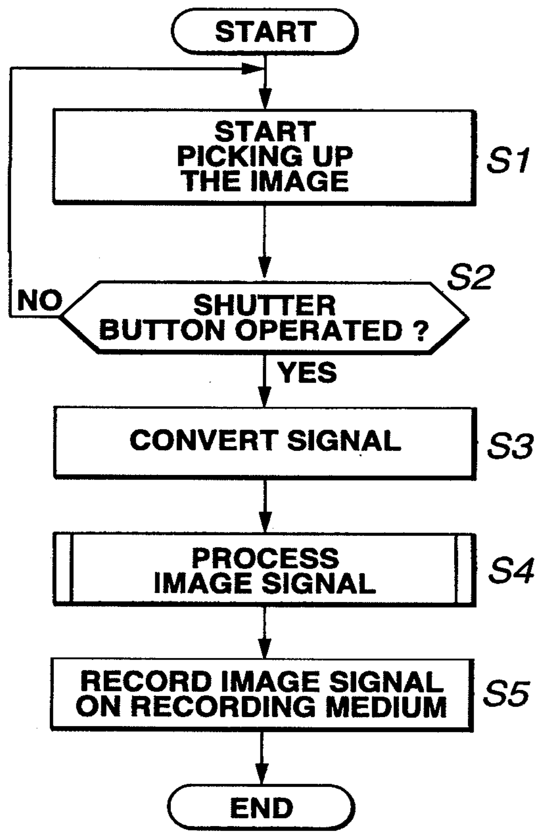
Y	G	C	Y
Y	G	C	Y
Y	G	C	Y
Y	G	C	Y

STRIPE

[FIG. 3]

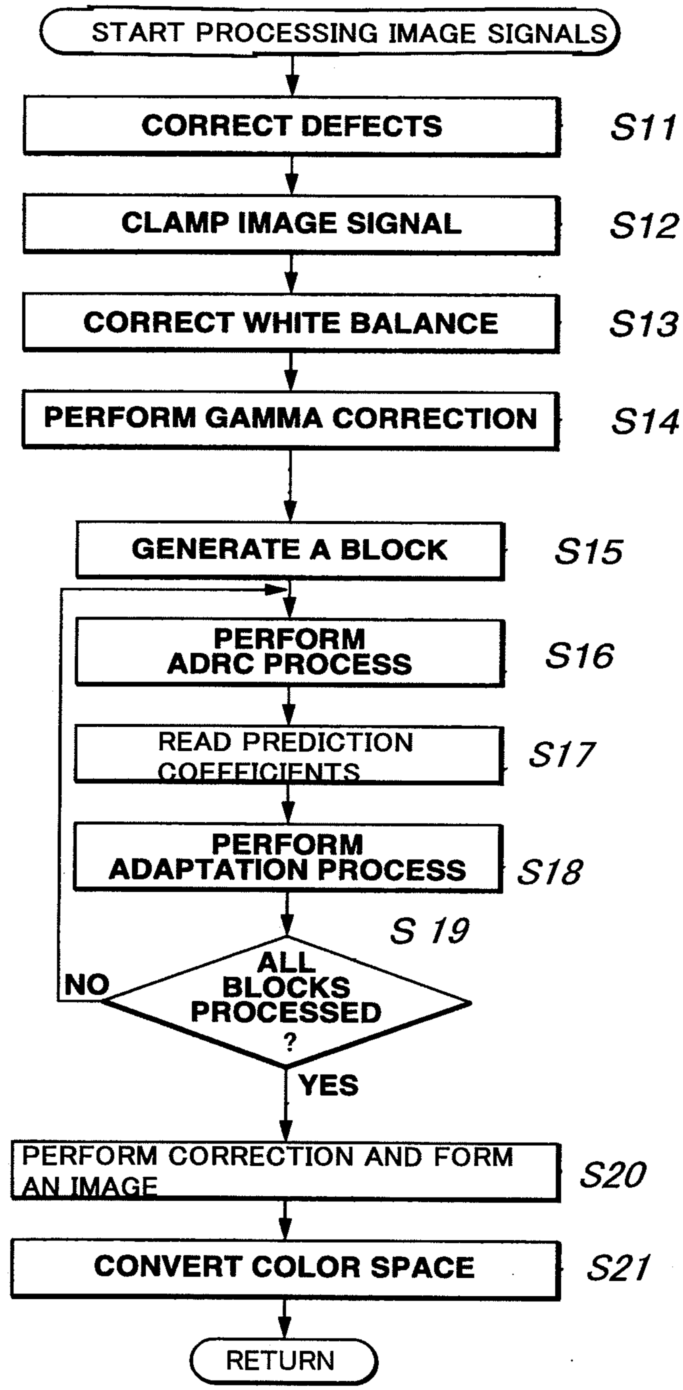

31
DEFECT CORRECTING SECTION
32
CLAMPING SECTION
33
WHITE-BALANCING SECTION
34
GAMMA-CORRECTING SECTION
35
BLOCK-GENERATING SECTION
36
ADRC SECTION
37
CLASSIFICATION PROCESS SECTION
38
ADAPTATION SECTION
39
COEFFICIENT MEMORY
40
CORRECTING SECTION
41
RGB MATRIX
RGB
YUV
IMAGE-SIGNAL PROCESSING SECTION 8

[FIG. 4]

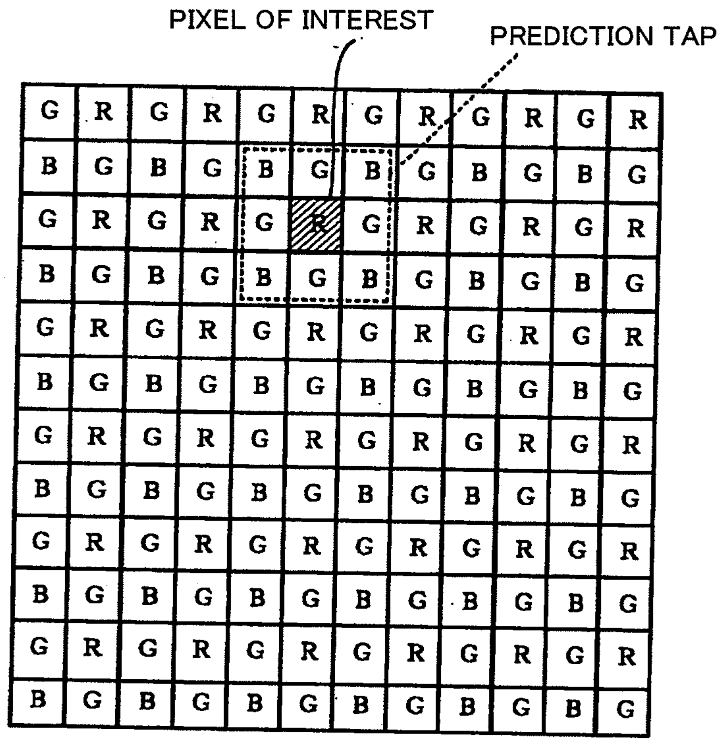


START
START PICKING UP THE IMAGE
S1
S2
NO
SHUTTER BUTTON OPERATED ?
YES
CONVERT SIGNAL
S3
PROCESS IMAGE SIGNAL
S4
RECORD IMAGE SIGNAL ON RECORDING MEDIUM
S5
END

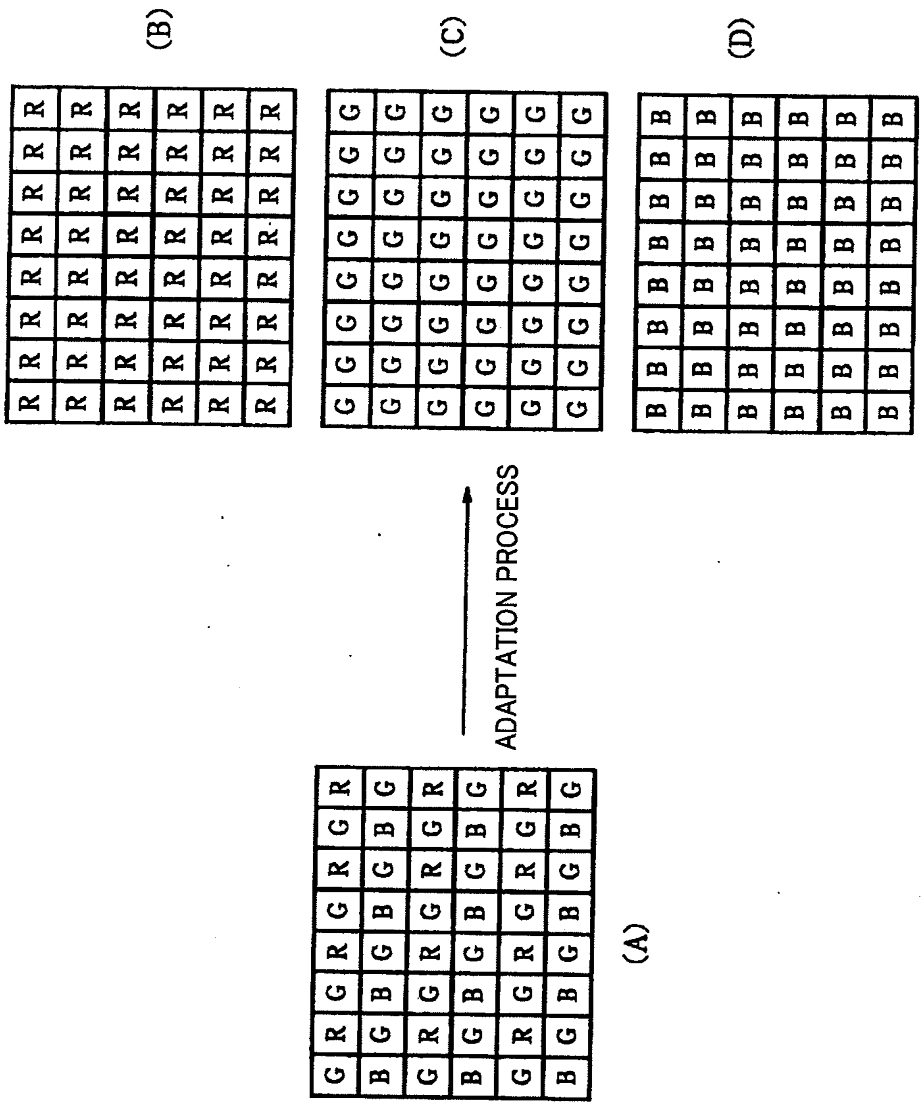
[FIG. 5]


START PROCESSING IMAGE SIGNALS
CORRECT DEFECTS
S11
CLAMP IMAGE SIGNAL
S12
CORRECT WHITE BALANCE
S13
PERFORM GAMMA CORRECTION
S14
GENERATE A BLOCK
S15
PERFORM ADRC PROCESS
S16
READ PREDICTION COEFFICIENTS
S17
PERFORM ADAPTATION PROCESS
S18
S 19
ALL BLOCKS PROCESSED ?
NO
YES
PERFORM CORRECTION AND FORM AN IMAGE
S20
CONVERT COLOR SPACE
S21
RETURN

[FIG. 6]



[FIG. 7]



[FIG. 8]

(A)

G	B	G
R	G	R
G	B	G

PREDICTION COEFFICIENTS FOR GENERATING R AT THE CENTER G OF THE MATRIX

G: −0.18302658	B: −0.00348441	G: −0.18293985
R: 0.49879314	G: 0.73624461	R: 0.50594424
G: −0.18439429	B: −0.00852019	G: −0.19665975

(B)

G	R	G
B	G	B
G	R	G

PREDICTION COEFFICIENTS FOR GENERATING R AT THE CENTER G OF THE MATRIX

G: −0.18229898	R: 0.50459112	G: −0.20290164
B: −0.00918055	G: 0.76466298	B: 0.01345021
G: −0.19371885	R: 0.50304269	G: −0.19857693

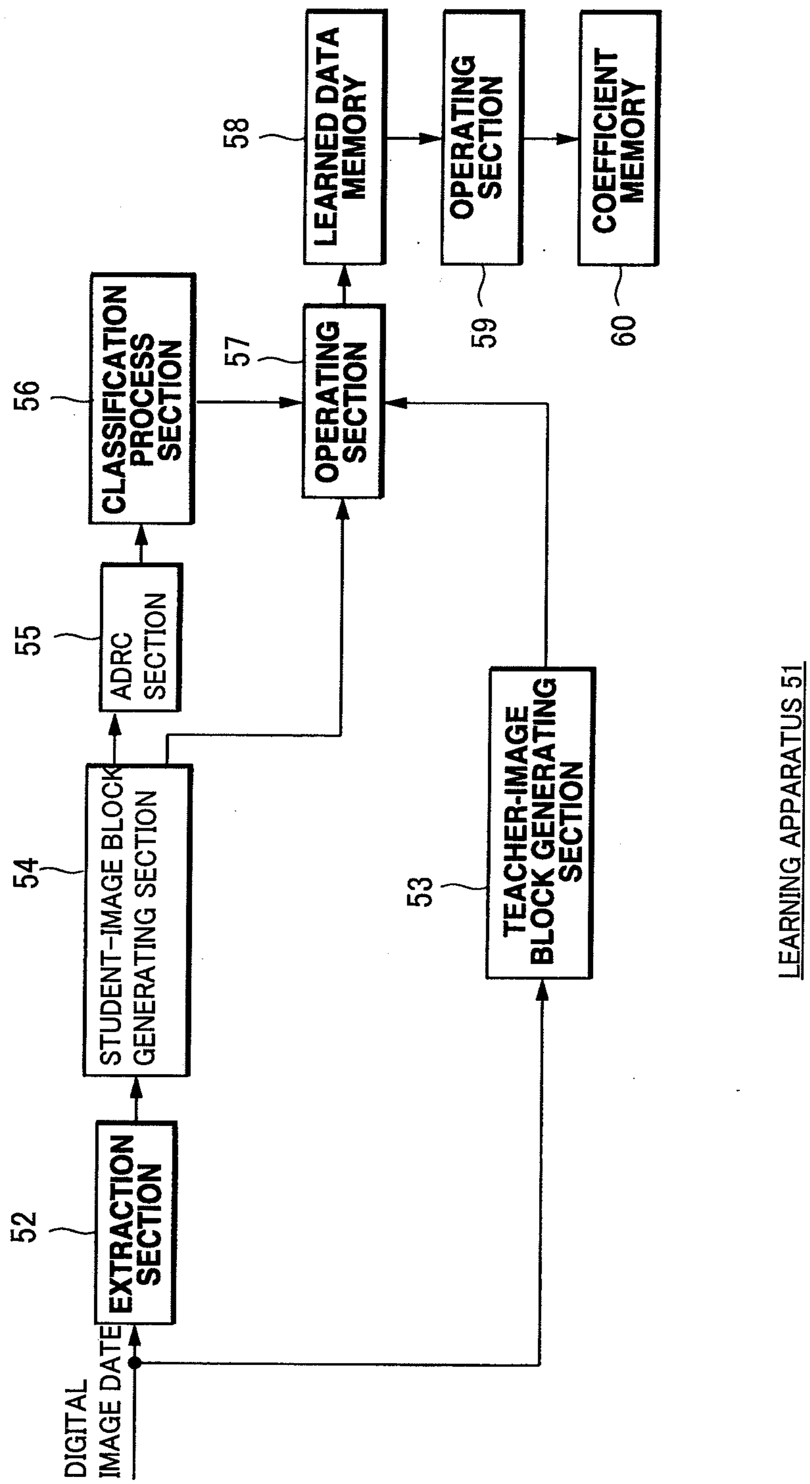
(C)

R	G	R
G	B	G
R	G	R

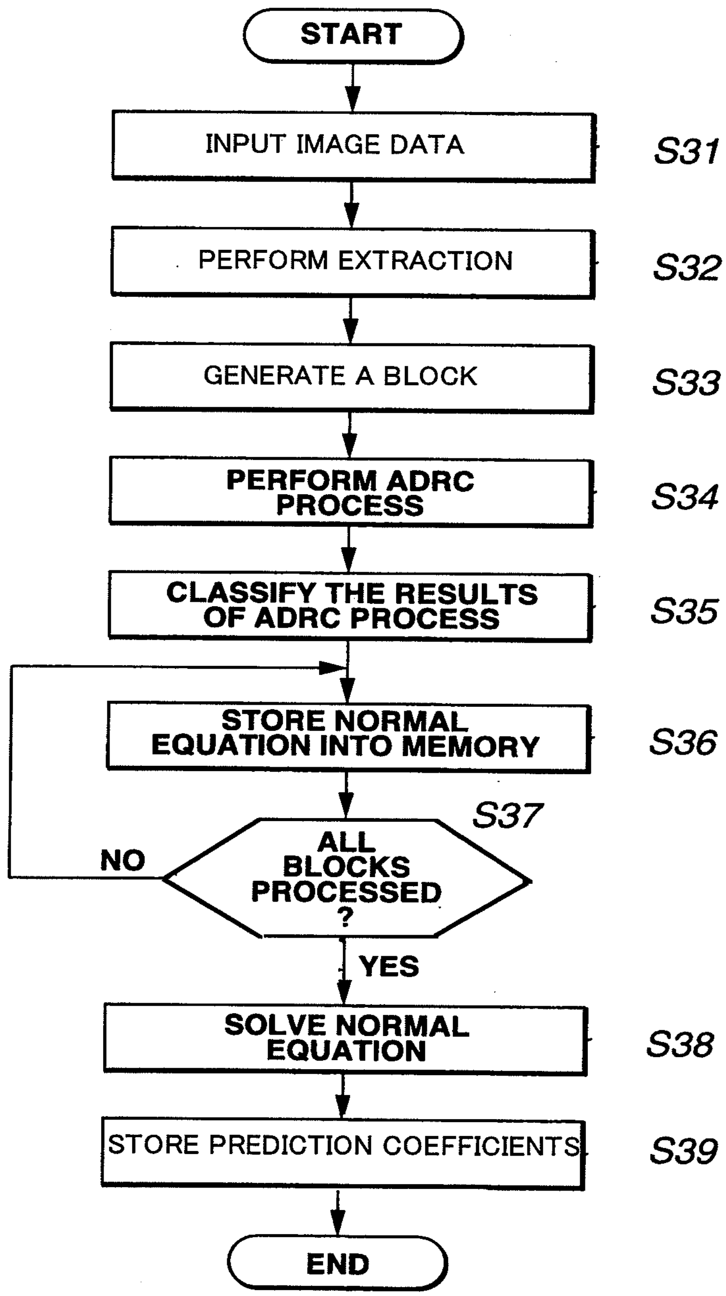
PREDICTION COEFFICIENTS FOR GENERATING R AT THE CENTER B OF THE MATRIX

R: −0.18302658	G: −0.00348441	R: 0.24498640
G: 0.49879314	B: 0.73624461	G: 0.03039153
R: −0.18439429	G: −0.00852019	R: 0.25799207

[FIG. 9]

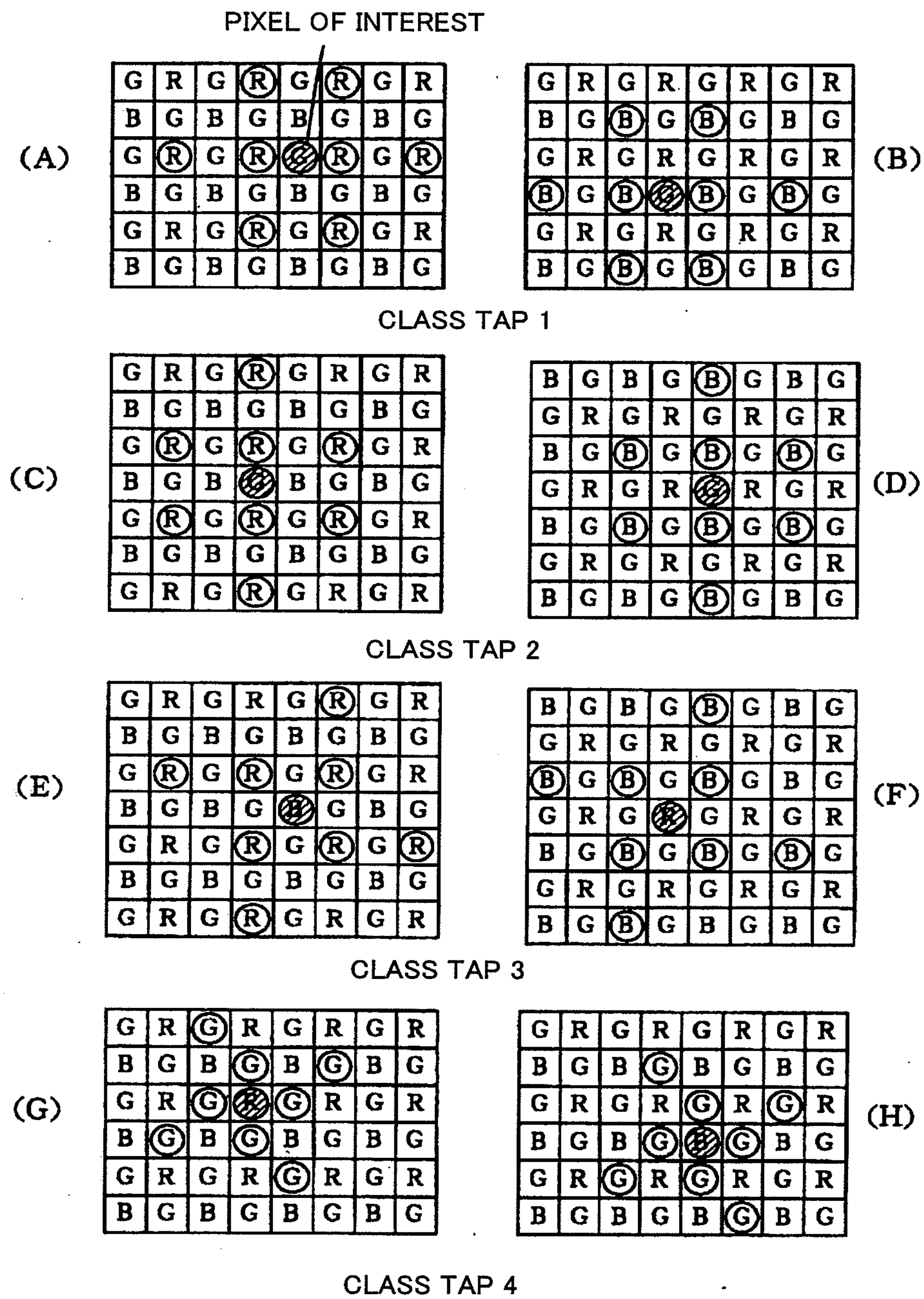

DIGITAL IMAGE DATE
52
EXTRACTION SECTION
54
STUDENT-IMAGE BLOCK GENERATING SECTION
55
ADRC SECTION
56
CLASSIFICATION PROCESS SECTION
57
OPERATING SECTION
58
LEARNED DATA MEMORY
59
OPERATING SECTION
60
COEFFICIENT MEMORY
53
TEACHER-IMAGE BLOCK GENERATING SECTION
LEARNING APPARATUS 51

[FIG. 10]



START
INPUT IMAGE DATA
S31
PERFORM EXTRACTION
S32
GENERATE A BLOCK
S33
PERFORM ADRC PROCESS
S34
CLASSIFY THE RESULTS OF ADRC PROCESS
S35
STORE NORMAL EQUATION INTO MEMORY
S36
S37
ALL BLOCKS PROCESSED ?
NO
YES
SOLVE NORMAL EQUATION
S38
STORE PREDICTION COEFFICIENTS
S39
END

[FIG. 11]



PIXEL OF INTEREST
(A)
(B)
CLASS TAP 1
(C)
(D)
CLASS TAP 2
(E)
(F)
CLASS TAP 3
(G)
(H)
CLASS TAP 4

[Document Name] ABSTRACT

[Abstract]

[Problems to be Solved]

To provide an image comparable to one formed by a three-plate CCD, by means of a single-plate CCD

[Means to Solve the Problems]

A single-plate CCD generates image data. The block-generating section 35 provided in an image-signal processing section 6 extracts a class tap and a prediction tap from the image data. The class tap and the prediction tap are output to an ADRC process section 36 and an adaptation process section 38, respectively. The ADRC process section 36 performs ADRC process on the input signal, generating a space class. A classification process section 37 generates a class code that corresponds to the space class. The prediction coefficient corresponding to the class code is read from a coefficient memory 39 and output to the adaptation process section 38. The adaptation process section 38 uses the prediction coefficient and the prediction tap, generating a color signal at the position of the pixel to be processed.

[Selected Figure] FIG. 3